Investigation of Material Wear Formation on Centrifugal Fan Impeller

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Abstract

This paper reports the investigation of wear formation on centrifugal fan impeller which was exposed to bagasse ash particles in the sugar process plant and to simulate what took place as particles impact on the impeller surface. Computational Fluid Dynamics has been used as a tool to simulate impaction of flow around the impeller to determine the impingement angles and velocity particles. After performing simulation using SolidWorks, angle of impingement was found to be low at the impeller inlet and gradually increase angle toward 90°, in reference to the blade root. The lowest angle found after simulation was 23°. This angle correlate with the theory mentioned for ductile material, stating that ductile material is susceptible to wear formation when the impact angle is between 15° and 45° with a peak at 25°. Computational Fluid Dynamics using SolidWorks has been verified by using a third-party company that worked on Creo 3.0 simulation. Research has revealed that material selection based on particles impingement angle, is key as when applied to centrifugal fans and related applications.

Keywords: Wear, Centrifugal Impeller Fan, CFD, impingement angle

1. Introduction

Many industries such as sugar mill plant, power generation, mining, smelters, platinum, steel and minerals process plant have been facing a huge problem with wear formation. Most of these industries have been seeking for solutions on what causes wear and how to minimize it. Sugar industry has been one of the leading industry that kept questioning manufacturer of process plant ventilation fans on how can wear formation be control and nevertheless, there still a grey area of knowledge in terms of how wear is formed on the fan impeller. There are many types of wear that have been already discovered by researches around the world. It has been determined that wear is one of the major problem that is highly subjected to fan impellers in sugar mill plant and is classified as erosive wear [1]. The biggest challenge of diagnosing wear is to understand the system, because wear is said not to be material problem but system problem [2]. The system is referred to the fluid substance that is conveyed inside the fan. Particularly in sugar mills, bagasse ash is the substance that is sucked from the boiler during combustion and pass through a filtration system where it gets entrapped and only clean air supposed to be discharged into atmosphere. Bagasse has been classified as fuel substance which is a by-product of sugar cane leaves, roots combined with soil and sugar cane stalk after being crashed to extract the juice [3]. The study is based on sugar mill induced draught fan operation, where an excessive amount of bagasse ash is not filtered by the venturi wet scrubber and is forced to pass through the fan. These bagasse ashes impact on the impeller and cause massive material loss. The study is about how bagasse ash impact on the impeller, at what velocity and what are the effects that are contributing to material loss that must be understood to mitigate the rate of wear on the impeller. Fig. 1 shows the schematic of the scrubber and centrifugal fan as well as the typical scrubber with a venturi to illustrate the working arrangement of the system.

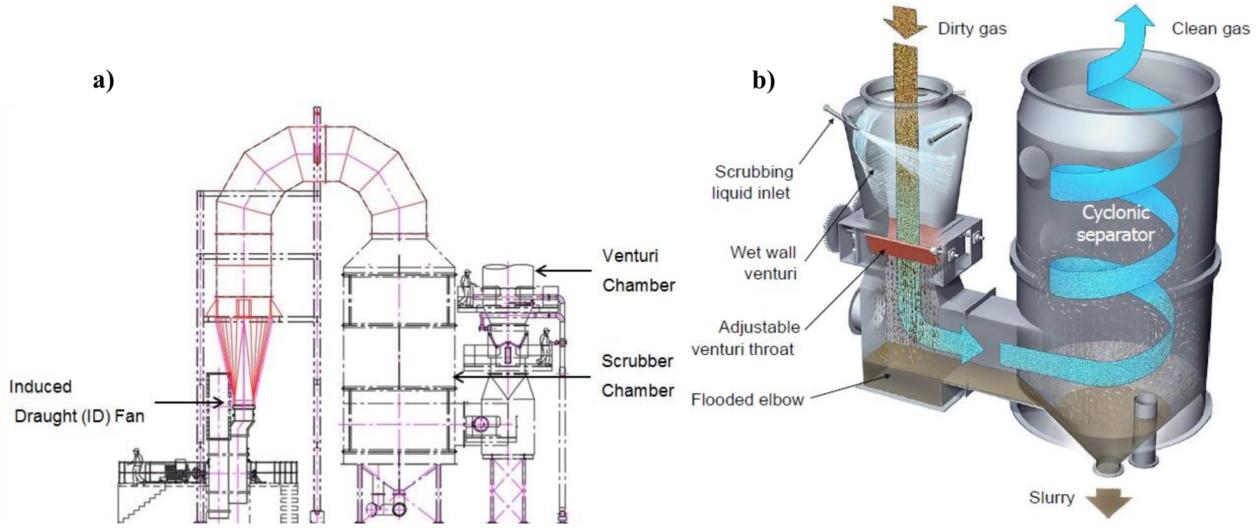

Fig. 1: a) Schematic diagram of scrubber and centrifugal fan and, b) Typical working arrangement of Venturi scrubber [4].

The main aim of this study was to perform a CFD and to correlate the results to wear damages found in situ and establish the uncertainty of what are the impingement angles in relation to impeller blades leading edges. The study of wear by other researchers has revealed that particles impact angles are one of the major factor that contribute to wear formation and these angles react differently to ductile and brittle materials [5,6]. The theory state that, lower and higher angle will have different characteristics. When a particle approached an eroded surface at a lower angle, between 5° to 30° and collide with the surface, during collusion shape of particle will affect the wear rate by trying to graze the surface or cut the surface. During this process, the shape of the particle does matter because particles work as a cutting tool and therefore wear takes part in a form of abrasion wear [6]. Basically, these are two surfaces rubbing each another and to resist wear rate, hardness of the component need to be higher. On the other hand, when angle of impingement is higher and is between 60° to 90°, to resist the wear, a ductile material will be required because most of the energy is transferred to the component and absorb all this energy as a compressive load. By increasing the particle size will increase wear rate, increasing the velocity will increase wear rate and impact angle will affect in either way although it is depended on the type of material being used [6].

2. Methodology

CFD simulation was computed by applying data used to select the fan operating duty, first condition was based on firing bagasse inside the boiler and the second was based on firing coal. This report will be focusing on bagasse firing condition. A 3D model of the fan was generated with an addition extension piece on the inlet side to allow turbulence flow to be given enough distance to be converted into smooth flow. A set of calculations has been performed to establish extra parameters required to setup the CFD project. Parameters such as total fan pressure rise, Reynolds number, fluid density, Impeller tip speed and velocities at fan inlet. For CFD setup, a project was created with analysis type to be internal and exclude cavities without flow condition. Rotating type was selected with local region under sliding. Under initial and ambient conditions, thermodynamic parameters required settings for pressure and temperature, where pressure was set using total fan pressure rise of 3145Pa and temperature was set to a value of 70°C which is referred to inlet fluid temperature. On the input data under setup computational domain, the model was set to be within the boundary and under rotational region, fan rotating speed of 615rpm was applied to enable the simulation to recognise that the impeller is rotating. The next step was to apply boundary conditions, a flow rate of $63.5m^3/s$ was applied on the inlet of extension piece and since the fan is discharging to the atmosphere through a stacker, a barometric pressure of 102000Pa as taken from the data supplied by the client was applied on the discharge side of the fan. The final setup was to establish goals and the following goals were created; to global maximum fluid density, global and surface velocities, surface total pressure and outlet flow rate.

Before running the simulation, global mesh setting was conducted and including a separate mesh that was conducted on the impeller only. After running a CFD, results were achieved and further analysed by creating cuts and surface plots. Since the study was focusing on velocities and how the fluid passes over the impeller blades and backplate, cuts plots on velocity were crucial factors and were plotted by using arrow pattern. To estimate projection of angle of attack, projected angles were represented by lines that are drawn tangential to the arrows of air path that are anticipated to be tangential to air streams. Angles of attack are measured between fluid streamlines and vertical plane of impeller blades leading edge. Streamlines are represented by black arrows moving in axial direction at impeller inlet and leaves the impeller chamber in radial direction. A CFD setup was successfully completed by setting up a project in SolidWorks package by using fan duty data provided by the consultant to establish boundary condition and goals needed to run simulation. Cut plots were plotted focusing on the flow pattern on the inlet of the impeller to determine impact angle and the second factor that was crucial to explore on the results was the highest velocity spots. Angles achieved from the CFD results were compared against erosion vs impingement angle curve established by TLT-Turbo R&D department [6]. The impeller was constructed from ductile material which is Weldox 700.

3. Results

Simulation was run, and desired results were achieved. The focus of the simulation was to determine angles of impingement as particles impact onto the blades and backplate of the impeller. Particle velocity also plays a major contribution on wear formation aided by particle size, shape and quantity passing through the fan. Therefore, study of velocity profile was a crucial factor to determine the cause of wear. Fig. 2, illustrates cut plot of velocity profile of the air entering and leaving fan distributed inside the fan casing and passing through impeller.

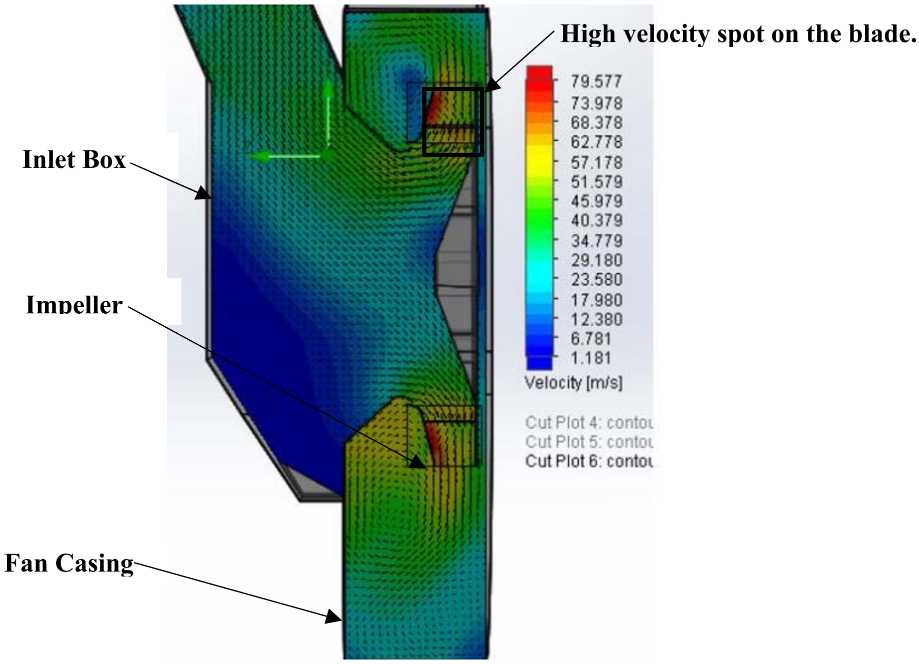

Fig. 2: Sectional view illustrating velocity profile as the air enter the fan

Velocities range from 0m/s to 95.5m/s maximum. Velocity at the fan inlet box ranges from 20m/s to 27m/s, with a gradual increase on the upper side of the fan inlet cone while the bottom side remains the same as the velocity on the fan inlet box. As air inters the impeller, the velocity dramatically starts to increase until the air leaves the impeller and discharges into the fan casing volute. High spot velocity discovered on the blade surface from CFD results has been indicated with high dense spots colour coding starting from green up to dark orange as marked on the blade viewing from the sectional view in Fig. 2 where velocity ranges from 44m/s to 78.5m/s maximum on the surface of the blade and this is the blade surface that is mostly exposed to high velocities.

When viewing Fig. 2 on a different plane as seen in Fig. 3, a second cut plot is taken to illustrate air distribution inside the fan casing volute and the impeller as the air leaves the impeller. Velocity values have been adjusted to reflect the highest velocity that is exposed to majority of blade surface. This sectional view shows the highest velocity on the blade as 79.6m/s and indicated by red spots and tangential to impeller outer surface of the velocity ranging between 53.5m/s to 66.5m/s. The volute shell area indicates that it is subjected to velocities ranging from 14.3m/s to 53.5m. On the discharge side of the fan casing on the upper left section indicates that less air is being conveyed over that surface. This has been recognised by maximum velocity of 14.3m/s that is shown on that area.

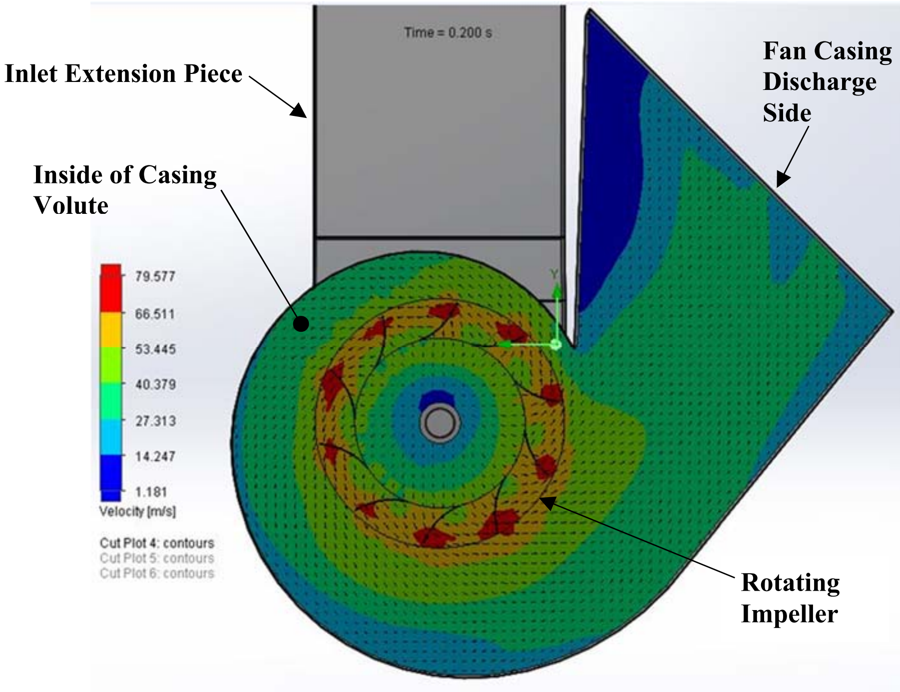

Fig. 3: Sectional view illustrating velocity profile as the air leaves the fan.

Erosive wear [6,7], is a function of particle velocity and impingement angle being supplemented by shape and size of conveyed particles. Either liquid or solid particles or combination of both comes with velocity and impinge on solid surface conveying some kinetic energy to the surface. During this stage an angle of impact will be an essential parameter. The main factors that takes part on wear formations is mass and hardness as well as velocity particle. Angles of impingement in this study have been measured from vertical plane of impeller leading edge blade represented by vertical black line and blue lines tangential to flow stream arrows. Fig. 4, illustrate angles of attack at the blade leading edge under bagasse firing condition, these are angles measured just before particles in the air path impact on the blade surface. It can be seen in Fig. 4 that impingement angle is low starting from the top blade leading edge and gradually increase toward the backplate with a maximum angle of +/- 75°. By taking a close look in Fig. 4, it can be observed that after the air has been discharged into the fan casing volute, a swirl is formed outside the impeller on the side of the shroud. This swirl is indicated by arrows impacting on the outer surface of impeller shroud. When taking a close look using Fig. 2, it can be observed that these arrows go back into the impeller through a 12mm gap between the impeller inlet cone and shroud ring. This can be interpreted by saying that fine particles leaving the impeller are brought back into the loop through swirl process and these particles have repeated impact with the upper blade leading edge.

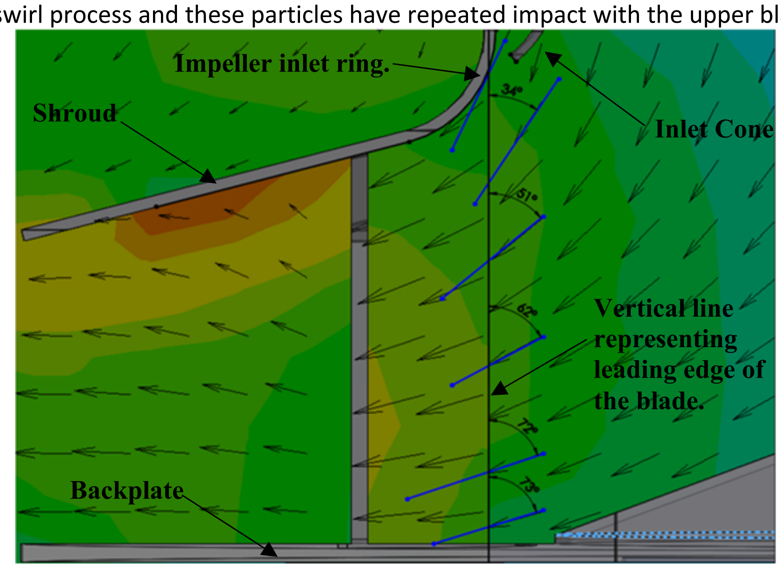

Fig. 4: Sectional view illustrating velocity profile as the air leaves the fan.

4. Analysis of CFD result

In erosive environments, particles that are normally entrained in a fluid can impact the wearing surface. The load between the particle and the surface, results from the momentum and kinetic energy of the particle [6,7,8,9]. The theory that has been tested by other researchers such as Dr. Dieter Holzdeppe from TLT-Turbo in Germany has been used to validate the CFD result [10]. The initial material construction of the impeller was Weldox 700 and it was later changed by the end user to S355J2+N. The theory was based on researching effects on different angle of attack against different types of materials. Dr. Dieter Holzdeppe [10] and his student has done a test on Weldox 700 and S355JR material to determine the effect of erosive wear due to different impact angles. The result reveals that both materials follow similar wear pattern with S690QL (equivalent to Weldox 700) resulting in reduced wear rate between 0° to about 55° and illustrate more wear rate between 55° and 90° as compared to S355J2+N material. The graph explain that wear rate formation is high between 10° and 55° for both materials, with both materials categorised as ductile as per the test. Fig. 5 illustrate the tested theory in full detail. With aid of comparison between CFD results from Fig. 4 and the graph in Fig. 5, it can be predictable that high rate of wear should be observed at the blade leading edge on the upper side of the impeller, where angles that ranges from 15° to 40° and with the increase in impact angles to maximum of +/-75° in Fig. 4, the expectation should be that from 40° up to 75° wear rate should be established at a lower rate and uniform.

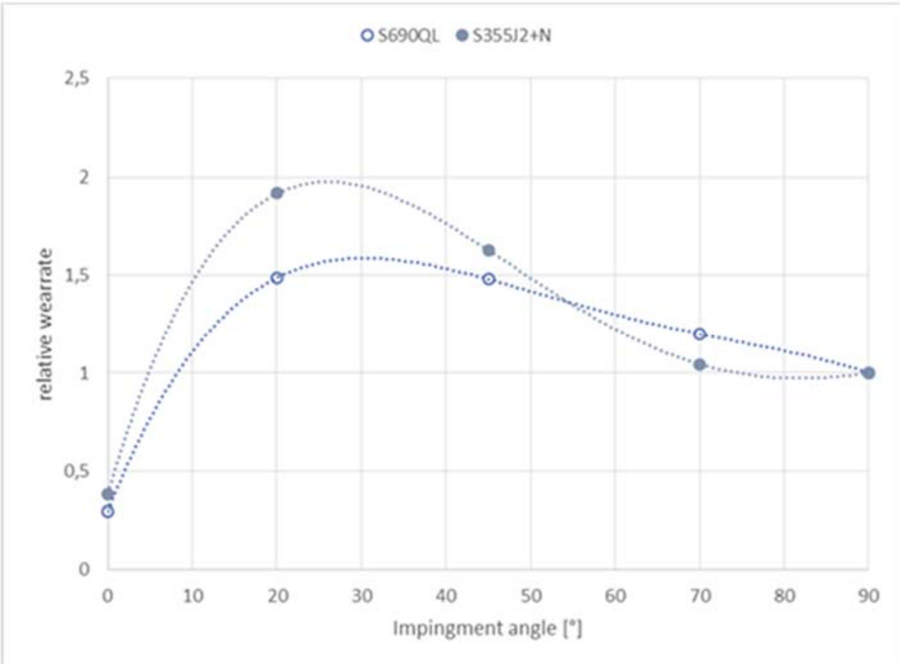

Fig. 5: Tested graph on wear rate vs. impingement angles [10].

The test was conducted to find out how impingement angles affect both materials. Results reveals that both materials follow similar pattern which gives high wear rate between 15° to about 55° and less wear rate between 55° and 90°. The explanation of why wear formation is high between 15° and 55° for both materials is because both materials have proven that are ductile as per the test. Brittle material gives opposite pattern as compared to ductile material. Wear rate curves between two tested materials are not aligned due to difference in material hardness. Harder material has proven to be more resistant to the formation of wear because of erosion.

A narration between results and pictures on observed wear development damages taken at situ was necessary to be implemented to verify whether CFD results can explain wear patterns in situ during operation. Correlation of CFD results with picture indicated in Fig. 5 has validated that CFD results correlate with the tested theory in Fig 5. The relation was based on conclusion of studying CFD results and identified areas that relate to literature as highlighted under this study. By comparing angles of impingement at the blade leading edge, with blade pictures photographed at situ, as shown in Fig.6, rate of wear was higher on the blade leading edge next to the shroud on the picture, the rest of the blade was subjected to a less uniform rate of wear. When relating damage on the picture with CFD result in Fig. 3, it was observed that the rate of wear correlates with angles of impingement revealed by CFD results and where the blade was subjected to less uniform rate of wear, it was also observed that the angle of impingement from the CFD result ranges between 51° and 75° and according to Fig. 5 wear rate took place at a lower rate with velocity ranging from 55° to 90°. Therefore, CFD results validated theory established by other researchers. The damages observed at situ can be applied in this study to implement a solution since all factors concerning impingement angles are verified. Blade was subjected to rapid levels of wear due to susceptible of ductile material at lower impact angles.

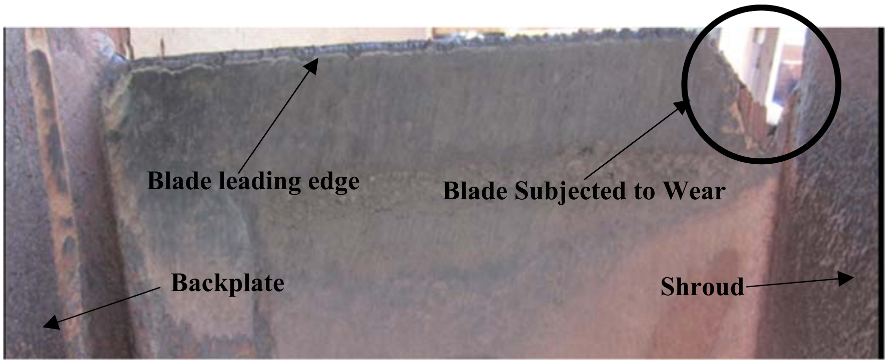

Fig.6: Picture photographed at situ showing wear damages on the blade.

Okonkwo [11] and Bagci [12], investigated the effect of velocity on the solid particle erosion rate of alloys, revealing that erosion rate is fully dependent on velocity. Particle velocity is one of the major factor that contribute to acceleration formation of wear [11, 12]. Therefore, an appropriate analysis on CFD results achieved after simulation must be conducted to understand the effect of velocity particles sliding over the impeller surfaces. This analysis of velocity particles has been inspired by the different velocities levels, that originate on the different parts of the impeller that has been revealed by the CFD results. Another correlation of results was based on particles velocity from CFD results against the blade picture photographed at situ indicated under Fig. 7. CFD results in Fig. 2 showing high velocity spot where velocity ranges between 44m/s to 78.5m/s maximum on the surface of the blade. The study has analysed the relationship between velocity range and the picture in Fig. 6, a comparison of the damages observed on the picture against the CFD results was necessary to validate the simulation. On the same spot of the blade subjected to high velocity, it was discovered that wear on the attached picture in Fig. 6 has been formed on the similar spot of the blade at situ. The outcome of the analysis in terms of particle velocity effects can be concluded that the verification of the CFD results was a success due to positive correlation of wear pattern in relation to high spot velocity on the blade surface. Therefore, CFD simulation was able to reveal the effect of velocity particles.

Fig. 7: Picture illustrating blade subjected to wear.

5. Conclusion

Comparison of literature review with patterns of wear damages found on the impeller has proven to be a success. This is a success as computational fluid dynamics performed to verify the formation of wear has correlated with the erosive wear seen on the impeller. Therefore, the study conforms to wear tribology previously investigated by other researchers through tests. The study has also revealed that impingement angles and high particles velocity plays an important role in accelerating rate of wear formation and these two factors might be supplemented by the high rate of aggressive particles passing through the impeller. This concludes that CFD simulation can be used as a reliable tool to investigate wear formation on rotating components.

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